

Integration of Marine Mammal Movement and Behavior into the Effects of Sound on the Marine Environment

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LONG-TERM GOALS

Integration of the Marine Mammal Movement and Behavior (3MB) model into the Effects of Sound on the Marine Environment (ESME) program contributes to the ultimate goal of creating an environmental assessment tool for activities that introduce high levels of sound into the ocean, particularly activities of the U.S. Navy.

OBJECTIVES

The objectives of the effort are to 1) expand the species library available for use in 3MB, 2) continue incorporating the ability to project environmental influences on simulated animal (animat) movement, 3) compare the animat implementation in environmental assessment procedures with static distribution approaches, and 4) incorporate the ability to emulate an animal's vocal behavior within the animat representation.

APPROACH

The proposed augmentation consists of several tasks, some of which will be completed in collaboration with Boston University (BU), Heat Light and Sound, Inc. (HLS) and Portland State University (PSU). Task 1 involves a continuing effort to acquire data for use in the development of species libraries. Task 2 involves a continuing enhancement of the 3MB model to permit better representation of the effects of environmental factors on marine mammal behavior. Task 3 is a quantitative assessment of the differences in impact estimates that result from the use of static animat distributions in simulated acoustic exposure scenarios and the use of animats (i.e. automatons that are mobile in space and time). Task 4 involves implementing the capability to have animats vocalize, thus providing ESME with a first step toward enabling the evaluation of passive acoustic mitigation measures.

Task 1 – Species Library Development

Development of species definitions (i.e. animats) requires access to information on the dive behavior and movement of marine mammals. A limited database of species definitions has been created based on the scientific literature available for certain species. This database will continue to be developed by first implementing information available in the literature for other species. The priority of species definition construction will be determined based on the quality of the data reported in the available literature and the likelihood of the marine mammal species' occurrence in coastal waters of the United

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States. Information sought will consist of statistical descriptions of dive depth, foraging dynamics at depth, vertical and horizontal swim rates, and temporal variations in dive behavior.

Task 2 – Environmental Influences on Animat Behavior

Currently, 3MB permits bathymetric characteristics to influence animal distribution and behavior. Depth limits on the initial distribution of animats and on the water depths that an animal might move into during a simulation are established in the creation of the species definitions. Additional environmental influences over behavior can be accounted for, such as diel alterations in dive behavior, slope aggregation, convergence on oceanographic features, etc. Initial enhancements will consist of modifying the transition probability matrices of the animats to include diel variability in behaviors and behavioral transitions. Follow-on enhancements will attempt to incorporate attraction/repulsion to or from environmental features. The most likely approach for enabling this behavior in animats would be through vector representation of oceanographic features (e.g. temperature gradients) which can then be used as weight in the animat directional movement algorithm.

Task 3 – Compare Outcome of Static Distribution and Animat Modeling Approaches

Historically, estimates of impact to marine mammals resulting from Navy acoustic activities have relied on 2-dimensional models of transmission loss from sources, and static distributions of animals without regard for animal movement in the vertical and horizontal dimensions. Alternative analyses have attempted to improve on the realism of impact estimates through the implementation of 3-dimensional transmission loss calculations and either 3-dimensional static distributions of animals (i.e. accounting for dive behavior) or the implementation of animat behavior, the latter being a 4-dimensional approach (i.e. animat behavior varies in time). Each of these approaches presumably affects the predicted impact to marine mammals due to the underlying assumptions that are applied. However, a systematic investigation of the variation in the magnitude of the approach-dependent quantitative estimate has yet to be made. In collaboration with HLS and PSU, Biomimetica will create several species that can be used to address each of the modeling approaches described above. Simulations will be run on a range independent environment using both a static sound source and a mobile sound source with a set duty cycle. Impacts will be calculated for different types of marine mammals crudely categorized as deep, mid or shallow water divers. Additionally, simulations will be performed on a range dependent environment to capture the type of variability in estimates that might occur when complex bathymetry contributes to complex sound fields. Results of the study will be published in a journal with an environmental modeling focus.

Task 4 – Animat Vocalization

Interest in enabling animats to vocalize has recently arisen because of a desire to test the feasibility and effectiveness of passive acoustic mitigation measures. The purpose of this capability is to provide a means for passive acoustic detection methods to be tested via simulation and to determine which methods demonstrate the most promise for implementation in the real world. Furthermore, simulation capabilities are desired that permit acoustic detection methods to be related to visual detections in the estimation of the abundance and distribution of marine mammals. This task would involve the enabling of vocalizations by animats with a focus on species-specific vocal patterns.

Communication with bioacoustics researchers will be undertaken to obtain samples of underwater marine mammal phonations which can be attached to an individual animat. Acoustic data files will also be obtained from data repositories (e.g. Cornell Macaulay Library of Natural Sounds) and other facilities with access to marine mammal sound archives (e.g. ONR). Data files will be standardized (i.e. re-sampled and adjusted for resolution) for use in the ESME model. Where possible, species-

specific information on phonation rates will be used to determine probabilistic models of sound production and will be incorporated as part of the animat's behavioral definition.

WORK COMPLETED

The species library has been expanded to include the blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), Cuvier's beaked whale (*Ziphius cavirostris*), Blainsville's beaked whale (*Mesoplodon densirostris*), and the harbor porpoise (*Phocoena phocoena*). Species currently under development or being updated include the harbor seal (*Phoca vitulina*), sperm whale (*Physeter catodon*), bottlenose dolphin (*Tursiops truncatus*), California sea lion (*Zalophus californianus*), and northern elephant seal (*Mirounga angustirostris*). The animat definitions for these species are anticipated to be completed by the second quarter of FY10.

Diel variability in dive behavior has been implemented into 3MB. The Species Builder program permits behavior transition matrices to be varied as a function of the time of day, thus permitting differences in nocturnal, diurnal, and circadian behaviors to be implemented. Efforts are currently under way to add environmental features as attractors/repulsors to the animats. The method used is based on the correlated random walk with directional bias feature already in use within 3MB. However, in this implementation, the directional bias will be opposite/toward the repulsor/attractor with the strength of the influence dictating the variance in the distribution of directions centered on the directional bias.

A first draft is being written comparing the static distribution of marine mammals method of acoustic impact estimates used in recent Navy range EISs (e.g. U.S. Navy, 2008) to the animat method of estimating acoustic impacts. The former assumes a static 3D distribution of animals in the environment based on density and distributions of residency at depth (based on known or estimated dive profiles). The latter uses dynamic simulations of marine mammals. The model comparison, utilizing a synthetic shallow diving and deep diving species, demonstrates that the static distribution method consistently provides the lowest estimate of impact. In contrast, higher estimates are observed with animats because the dynamic approach accounts for the possibility that animals may be exposed more than once during a simulation, with the potential for differing exposure levels during each exposure. Furthermore, the animat approach provides measures of variance, which are important in determining the confidence in the prediction, and allows estimates of the probability of spurious scenarios (i.e. high numbers of harassments) to be made.

In addition to the accomplishments listed above, numerous enhancements to 3MB and the associated Species Builder have been made. Many enhancements are related to the graphical user interface (GUI) of each program. Examples of the enhancements include color-mapped bathymetry, easier extraction of data according to the times of the exposures, user-determined data output, more seeding options for initial animal distributions, and graphical representations of species behaviors at the time of species definition creation (thus permitting on-the-fly observation of parameter changes).

RESULTS

Comparisons between the static distribution of animals in the environment for impact assessment and that using dynamic animats have demonstrated a notable difference in the levels of impact prediction provided by the two methods. The latter approach typically produces higher estimates and has the advantage of providing estimate variances and the ability to predict spurious events. The

implementation of diel variability in dive behavior, which is becoming increasingly evident as a component of most species' behavioral repertoire, permits the differences between these methods to be more thoroughly explored since the static distribution method does not account for variation in dive behavior with respect to either time or environmental condition.

It is apparent that sufficient information for the creation of robust species definitions is difficult to obtain based on literature searches alone. Following creation of the base species dictionary, efforts will likely need to be extended to the primary investigators that hold the dive data from various tagging efforts. These data often do not appear in the literature for years following collection and often are presented in a summary format that prevents detailed models to be developed.

IMPACT/APPLICATIONS

The integration of the ESME program with the capability to emulate the dive and movement behavior of marine mammals provides a significant advantage to modeling environmental impact than do past approaches used in Navy environmental assessments (EA) and impact statements (EIS). Many previous methods have been statistical or pseudo-statistical approaches that estimate impact by reduction of animal distributions in time and space. Although such approaches may be suitable for range independent environments, they do not approximate the real world and may miss important features of animal behavior and may over- or underestimate impact. Marine mammal dive behavior and distribution are both influenced by the environment. By implementing animat dive behavior and movement, and having each animat respond to the environment and emulate behaviors according to the species they model, a more realistic assessment of impact can be obtained. Such assessments will have benefit to both the management of animal stocks and in providing relief from legal issues grounded on prior modeling assumptions and outcomes.

RELATED PROJECTS

None.

REFERENCES

U.S. Navy. (2008). Hawaii Range Complex: Final Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS). Washington, DC: U.S. Department of Defense.